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RESEARCH AND DEVELOPMENT HIGH PRIORITY AREA (HPA) TRUCK-PAVEMENT INTERACTION

Pavements

Objectives

Determine relationships between heavy vehicles, environmental conditions, pavement response, maintenance, and rehabilitation to support decisions for a national policy on truck size and weight, axle/tire/suspension characteristics, cost allocation, and alternate pavement design and rehabilitation strategies.

Scope

Full-scale field tests (on instrumented pavements with instrumented vehicles) and laboratory tests will be combined with computer simulations to form the basis for research conducted under the Truck-Pavement Interaction (TPI) High Priority Area (HPA). Emphasis is placed on mathematical modeling of the dynamic action of trucks and the reaction of the pavement to forces generated by trucks. Expanded laboratory and field tests will serve as the validation and calibration mechanism for the mathematical models developed.

As part of this effort, computer simulation models to predict pavement environmental effects will be validated for consideration in predicting pavement performance. Pavement rehabilitation and maintenance life-cycle cost relationships needed for implementation will then be integrated with the truck-pavement damage models to form the overall pavement damage preservation cost models.

Background

To the public, one readily apparent product of truck-pavement interaction is damage to the pavement caused by heavy trucks. Lower costs of goods and services (due to economical and efficient transportation) are also products. The importance of productivity is, however, becoming more critical as global competitiveness continues to increase. There is a need for more economical transportation of goods and services, generally provided by heavier payloads, while preserving and upgrading the service life of our Nation's pavements. Currently, tradeoffs are made through the political process without the benefit of strong technical support.

This HPA will provide technical information to help optimize decisions concerning truck size/weight policies and pavement engineering/management issues. The program will also aid in improving truck design to reduce or minimize damage to the highway system. Knowledge of the impacts on pavement performance will permit a more effective maintenance intervention and preservation strategy for the highway system.

Research Facilities

The TPI research program will use a variety of unique full-scale, truck-pavement-related test facilities. Each laboratory resource provides different, but interrelated pavement/vehicle analysis capabilities. They presently include the FHWA Test Road Facility, a prototype dynamic truck actuation system called DYNTRAC, the Pavement Testing Facility (PTF), and the Pavement Isothermal Test System (PITS).

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- The FHWA Test Road contains two full-scale flexible pavement test sections capable of accommodating a variety of vehicles traveling up to 88 km/h (55 mi/h). The main feature is strain and deflection instrumentation that is strategically located within the pavement sections to measure primary responses to moving truck loads.

- The DYNTRAC laboratory was constructed to study the nature of dynamic forces on pavements induced by heavy trucks. This system measures the dynamic forces exerted by the wheels of heavy vehicles as they are subjected to vertical oscillations from four hydraulic actuators simulating known road profiles.

- The PTF includes a fixed-speed, rolling-wheel accelerated loading apparatus called the Accelerated Loading Facility (ALF). It provides valuable information on ultimate performance (fatigue cracking and rutting of flexible pavements) within months, enabling prediction of problems and likely modes of failure long before they would occur on inservice highways.

- The PITS consists of two 3.4 by 3.4 by 2.72 m (10 by 10 by 8 ft) concrete chambers containing full-scale pavements in a controlled temperature chamber. Test pavements can be subjected to multiple combinations of controlled stress, fixed-position loading needed to simulate the wide variety of load magnitudes and frequencies typical to highway pavements.

Research Program

Four main phases of research can be identified in this HPA.

PHASE 1: Load Equivalency Factors

Develop primary response load equivalency factors that express pavement damage attributed to vehicles having different weights and axle load distributions.

PHASE 2: Primary Response Analysis

Verify and calibrate layer theory and finite element models. This phase deals with the effects of load on structural responses of pavements and the ability to estimate these effects using elastic and visco-elastic theory. These responses, typically strain and deflection, are complex functions of pavement structure, loading characteristics, and environmental conditions. For example, the response from multilayer deflectometers in the test road will yield compression within each layer during loading. This time-compression trace for each pavement layer offers a unique opportunity to study the load response of the pavement system.

PHASE 3: Vehicle/Pavement Interaction

Determine the dynamic effects experienced by pavements as a result of impact loadings caused by the bouncing motion of vehicles. The program will combine full-scale field tests, laboratory tests, and computer simulations. For instance, in the field tests, several types of trucks with different suspensions will be run on instrumented test roads. Trucks will be equipped with wheel-force transducers to record forces transmitted to the pavement. Pavement response data will be obtained from embedded strain gauges.

PHASE 4: Life-Cycle Cost Analysis

Available life-cycle cost (LCC) and environmental models will be combined with the truck-pavement interaction models. The economic models will be upgraded and combined with the truck-pavement LCC models to form the overall pavement damage/preservation cost model.

Completed Research

The FHWA Test Road was constructed in August 1990 to provide a thick and a thin pavement test section on an access road to the Turner-Fairbank Highway Research Center. The test sections [each 100 ft (30.5 m) long]were designed to accommodate strain and deflection instruments placed along the center of the left wheelpath of each section. Included were the following instruments:

Longitudinal H-Type Strain Gauges

These gauges were installed in a line .305 m (1 ft) apart to measure the dynamic response of the thick pavement section.

Longitudinal Alberta Research Council (ARC) Strain Gauges

These gauges were placed to study strain in the pavement under controlled loading conditions. They were placed in a pattern to cover the vehicle wheel print.

Deflectometers

These instruments were installed for use in phases 1 and 2 of the research program and consisted of both single and multilayer types. Both types were installed in each section.

Initial testing has been completed on the two instrumented test road sections. This testing included three vehicle types, three axle loads, two pavement thicknesses, and two tire pressures. A single-unit, two-axle vehicle was used to apply the standard 172-kg (18-kip) load.

A prototype dynamic truck actuation system, DYNTRAC, has been fabricated and is undergoing shakedown testing. It has four hydraulic actuators, one for each tire or dual-tire unit of a two-axle truck. The four actuators can also be used to support each dual-tire unit of a tandem suspension trailer with the front of the trailer supported by a custom-designed fifth wheel structure (to be developed) or a stationary tractor.

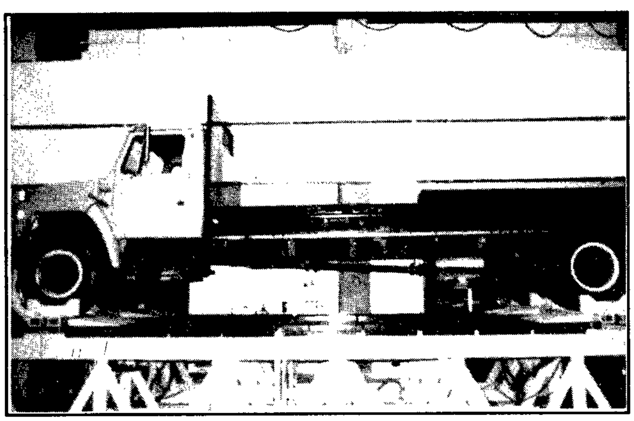

Figure 1. Dynamic truck actuation system.

DYNTRAC is equipped with two computer systems—for control of the hydraulic actuators and data acquisition. A measured or synthesized road profile is transformed into vertical displacements of the actuators. The input profile contains two columns, one each for the left and right wheel tracks. The rear actuator motion is the same as the front, in the same track, time delayed depending on the simulated speed and wheelbase. The data acquisition system collects, stores, and displays results of measurements of actuator positions, accelerations, and differential pressures across actuator pistons.

Research in Progress

Wheel scales are currently being designed to measure dynamic tire loading. The wheel scales will be installed on the actuators and their outputs will be added to the DYNTRAC data acquisition system.

A two-axle truck will be used as a primary test vehicle. The truck has been instrumented and equipped with an onboard data acquisition system. The wheel force transducers are under development and are being replaced by strain gauges installed on the truck axles. The strain gauges and accelerometers mounted on the axles are used to calculate tire forces.

Three types of tires were selected for the testing program: conventional radial tire, low-profile radial tire, and wide-base (or super single) radial tire. Four trucks were selected for the study, with each truck representing a different combination of suspension type and axle configuration:

- Two-axle truck with leaf spring suspension.
- Two-axle truck with air spring suspension.
- Five-axle tractor semi-trailer with leaf spring suspension.
- Five-axle tractor semi-trailer with walking beam suspension.

The third approach to the problem of truck-pavement interaction (besides laboratory and field tests) is computer simulation. Available computer programs vary in size and complexity from relatively simple (executed on personal computers) to sophisticated (requiring high-speed mainframe machines). However, even the most sophisticated programs are only as accurate as the estimates of model parameters employed in the simulation. Models currently being evaluated for use in this program include rigid/flexible pavement primary response and damage models, environmental models, truck dynamic models, and economic models. Considerable effort has been directed in this study toward identification of the input parameters needed for each of these type models. For instance, rutting material parameters and fatigue cracking coefficients are being developed for the new VESYS flexible pavement models from the accelerated load test findings at the ALF. Parameters needed for the truck dynamic models were measured on a two-axle truck using facilities at the Altoona Bus Research and Testing Center (ABRTA). These include wheelbase, weight distribution between axles, truck center of gravity position, roll, pitch and yaw moments of inertia, suspension spring rate and Coulomb friction, and so on. Tire characteristics were measured by the Goodyear Tire & Rubber Company using the force-pin method. The measured tire characteristics included net and gross contact area, load-deflection curves, and contact pressure distribution.

Future Research

The main independent variables in the DYNTRAC test program are type of tire, inflation pressure, type of truck and truck suspension, truck speed, and road roughness. The results of the tests with the selected vehicles facilitate comparisons between different suspensions used on similar types of trucks and between trucks with different axle configurations, but the same suspension type. Vertical tire load is tested at four levels, while tire inflation pressure and truck speed are varied at three levels. Finally, longitudinal elevation profiles of three road sections of relatively low, medium, and high roughness (measured with a road profilometer) are used as input signals on DYNTRAC.

Field tests will also be conducted with the instrumented truck on the medium roughness road and on the test road. The measurements of tire forces and truck dynamic response obtained in the field tests will then be compared with the same measurements obtained on DYNTRAC. It is recognized that tire forces as well as truck accelerations and displacements measured on DYNTRAC will not be identical with the analogous measurements recorded in the field tests. However, an analysis of the discrepancies between field and laboratory data that occur under various test conditions will provide important information for determining the validity of the DYNTRAC system as a laboratory tool for simulating truck dynamic response to road roughness. Coordinate activities are currently being planned with England, Canada, and Finland through OECD's Coordinated International Research Program.

Summary

The prediction of pavement response under surface loads constitutes an important component of mechanistic analysis of flexible pavements. These responses are a function of both the pavement structure and the environmental conditions. Factors such as tire pressure, axle load, axle configuration, vehicle speed, layer thickness, and time dependent material properties also influence the response.

The experiments planned under this program coupled with the proposed analytical developments will produce information that will increase our knowledge of the interactive relationship between vehicle dynamics and pavement behavior.

Distribution - This High Priority Area (HPA) summary is being distributed according to a standard distribution. Direct distribution is being made to the Regions and Divisions.

Key Words - Pavements, pavement performance, pavement evaluation, truck, truck design, truck dynamics, truck pavement damage.